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Simulating nitrogen dynamics for sustainable farming systems

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Abstract: Nitrogen (N) is a critical element for plant growth resulting in the application of N fertilisers to most cropping, and some pasture production systems. Nitrogen that escapes the soil causes environmental harm to marine and aquatic environments and exacerbates global warming. Thus, N fertilisers and N applied to fields in other forms (e.g., animal returns) need to be managed to both enhance productivity and minimise environmental impacts. The Agricultural Production Systems sIMulator (APSIM; Holzworth et al., 2018) is a well-developed tool to help achieve these balanced outcomes. However, the number of processes that need to be simulated and the available data for building and/or testing models of these processes pose challenges. In this presentation, we look back at the history of simulating N cycling in APSIM and explore advances in its model development and application.

Keywords: *APSIM, nitrogen loss, fertiliser management, enhanced-efficiency fertilisers, nitrification inhibition*

1. HISTORY OF SIMULATING N CYCLING IN APSIM

In APSIM the soil provides a central focus, as “crops, seasons, and managers come and go, finding the soil in one state and leaving it in another” (McCown et al., 1996). Its SoilN module, responsible for soil carbon (C) and N cycling, was hence among its earliest modules developed (Probert et al., 1998). As a core module it has been included in every APSIM simulation since. Its concept is simple: C and N flows between a series of conceptual organic C pools of differing stability and N content, linked via mineralisation and immobilisation with mineral N pools for ammonium and nitrate. Due to its agricultural focus, it also includes a dedicated urea pool, although a range of N fertilisers and organic products can be applied. Indeed, along with plant N uptake, surface residues and belowground fresh organic matter returned by the plant modules form an important link between the crops and the soil. Over time new applications prompted model enhancements, e.g., nitrous oxide emissions and N in runoff.

Initial applications of the SoilN module focussed on the role of legume ley pastures for N supply to cereal crops in subtropical and semi-arid tropical Australia (e.g., Probert et al., 1998). Among the more recent studies, the APSIM model has been used to assess soil and fertiliser N management strategies, to evaluate crop and system N use efficiency, to explore opportunities to mitigate nitrous oxide emissions, and to characterise and evaluate management strategies aimed at reducing N leaching losses (Verburg, Pasley et al., 2025).

2. REVIEW OF N MODELLING CAPABILITY

The increased sustainability angle of applications, including environmental impacts and climate change effects, has placed new expectations on the accuracy of the model outputs. This prompted a large review of APSIM’s soil N modelling capability, which is documented in full in Verburg, Pasley et al. (2025). The review across 131 model-data comparisons, highlighted model strengths, model challenges, cautionary tales and next steps (Figure 1).

Model Strengths	Model Challenges	Cautionary Tales	Next Steps
Strong performance across all processes	Sensitivity to initialisation approach	Parameter optimisation focused on one system	Test prototypes (NH_3 volatilisation and runoff)
Customisable coding structure	Uncertainty in measured data	Simple measurements for complicated processes	Test proposed parameter changes
Robust model review process	Daily timestep simulating sub-daily processes	Equifinality in carbon pool parameterisation	Capitalise on advances in measurement techniques and process understanding

Figure 1: Highlights from the review into APSIM’s N modelling capability (from Verburg, Pasley et al., 2025).

3. ADVANCES IN MODEL DEVELOPMENT

The review findings inform several current model development activities. This includes work on formal inclusion in APSIM release of ammonia volatilisation (Pasley et al., 2025b) as well as the ability to represent slow release of fertiliser N and inhibition of nitrification and urease activity. Like many others, these developments were first built as prototypes using the flexible logic of APSIM's manager module. Indeed, this flexibility in APSIM was identified in the review as one of APSIM's strengths and in APSIM Next Generation the coding opportunities are further enhanced. In moving from manager code to structural flexibility within APSIM itself, we look to generalise the implementation so that future use cases are also catered for. For example, the implementation to allow user-specification of fertiliser composition, rate of release, transport, degradation, and any impacts the solutes have on different processes.

Data are key to these developments with several projects underway to collect data for testing. Where data is insufficient, a first step to implementation can be sensibility and sensitivity testing. Improvement of model parameterisation, for both the existing model and new developments, is also a current research focus. For example, work to describe the sub-pools of surface organic matter, organic matter additions and fresh organic matter in the soil more flexibly (drawing on Probert et al., 2005) and to provide practical guidance for spin-up approaches (Pasley et al, 2025a) to build on the soil parameterisation protocols described in Cichota et al. (2021).

4. ADVANCES IN MODEL APPLICATION

Many recent advances in APSIM model applications have similarly drawn on APSIM's flexible manager coding. This includes smart ways to represent complex rotations and their management to explore the benefits of novel management practices or risks associated with different farmer decisions, but also the building of prototypes to reflect enhanced efficiency fertilisers and model biological nitrification inhibition by root exudates (Garba et al., 2025). In turn some of these applications lead to further model development and testing, especially when the new applications mean that simplifying assumptions no longer hold. For example, APSIM's past assumption that crops only take up nitrate, which is acceptable if ammonia is rapidly nitrified but no longer holds in the presence of inhibitors and the crop's preference for form of N can come into play. The modelling of root exudates could also inspire a closer look at their role in organic C cycling. This continues the application – data – development cycle.

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